

ELECTRONIC BALLAST

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ABSTRACT

Nowadays, the development in technology causes some intelligent groups to create many ideas in producing something useful for human life. The increasing of electrical cost will give more advantages to the engineers to make research in producing the electrical equipments that can save electrical energy. One of application is electronic ballast. The electronic ballast is targeting the most of peoples because everyone needs the electrical energy for lighting system whether at home, office, school, mosque, factory and so on. The electronic ballast specially made to replace the conventional choke in fluorescent lamp. Electronic ballast can control the lamp power more easily and has higher efficiency since it uses the power semiconductor devices with better switching method. Even the cost for produce the electronic ballast is more expensive than conventional choke, it still has more advantage in lifetime operation because it is greater than conventional choke. By using the 240 VAC as a voltage source, the combination of L-C circuit will be acts as filter in electronic ballast circuit to eliminate the spikes and smoothes out the steps in the current waveform during start-up.. Furthermore, the introducing of IR2156 ballast controller IC in electronic ballast circuit can make the operation of lighting system will improved. The IR2156 IC has include the programmable preheat frequency, programmable preheat time and programmable over current protection and internal ignition ramp which can make sure the safety of this system is guaranteed. Consequently, the high frequency can obtained and the efficiency of lamp operation can improved. Therefore, everyone can save his or her money to pay the electricity bill since the electronic ballast used in fluorescent lamp

CHAPTER 1

INTRODUCTION

1.1 Background

This chapter explains about the overview of electronic ballast, the objectives of the project, project scopes and thesis outline. This project is suitable for lighting application.

1.2 Electronic Ballast Overview

Electronic ballast is ballast that uses semiconductor components to increase the frequency of fluorescent lamp operation, typically in the 20 – 40 kHz range rather than 50 Hz normally used in conventional ballast. The conventional ballast was used today is need a starter to ignite the lamp and fluorescent lamp will flick during the ignition process. This flicker is actually will cause the high starting current or in-rush current occurs during starting process. This event will consume more power demand during starting condition and consumers are necessary to pay the electricity bill for

every month with high rate of value. Consequently, waste energy will occur in electrical energy and so, waste money for consumers.

However, electronic ballast needed to design for improving the lighting system of fluorescent lamp. Based of potential in electronic ballast, most of all problems at above can reduce or may eliminate. High frequency, which produces in electronic ballast, will improve the efficiency of lamp operation. The life of electronic ballast is longer than conventional ballast because the flicker effect is free and less noise in operation.

1.3. Objectives

The overall objective of this project is to produce the high frequency (20kHz – 40kHz) electronic ballast which is capable of achieving 0.95 power factor for use with 18 W fluorescent lighting systems. However, the objectives are to free from flickering in lighting system and reduce the noise such as Electromagnetic interference (EMI) and Radio Frequency Interference (RFI) so that the lamp's life can be longer. Other objectives also are to make the energy consumption in fluorescent tube light fittings and consume the electrical energy to consumers with low cost of operation and to avoid the need for starter to light up the fluorescent lamp.

1.4. Scope of Project

In this project, I need to design and construct electronic ballast for use with a fluorescent lamp. The type of fluorescent lamp that I will use is T8 / 18W tube because this type is very popular in use for most of the place like classroom, home, office, mosque, café and so on. The circuit design for my project should be match with electrical line voltage requirement and suitable with fluorescent lamp type. This requirement is so important because to prevent any explosion or leakage in electronic ballast.

The components that need to use in electronic ballast circuit also must have suitable rating and value for each circuit stage so that the circuit can be function. The 240 VAC supply will be use to supply the power in fluorescent lamp because the most of lighting system for fluorescent lamp today are using AC source as a supply.

1.5 Thesis Outline

Chapter 1 explains the background and overview of electronic ballast project. The project criterion is based on the 240VAC voltage source and 50 Hz that is used in Malaysia.

Chapter 2 focuses on the methodologies for the implementations and designing of electronic ballast. It gives a brief review and correlation of all methods in producing electronic ballast for T8 and 18-watt fluorescent tube.

Chapter 3 explains and discuss about the meaning of electronic ballast, how electronic ballast works, the advantages of electronic ballast and the detail of implementation of electronic ballast.

Chapter 4 discusses all the results obtained in analysis of project. All discussions are concentrating on the result and performance of overall project.

Chapter 5 discusses the conclusion of the overall project. This chapter also discusses the problem and the recommendation for this project.

CHAPTER 2

LITERATURE REVIEWS

2.1 Electronic Ballast Overview

Nowadays, electronic ballasts for fluorescent lamps are popular in many lighting systems. Typical electronic ballasts consist of two power stages. The first stage is a power factor corrector for regulating the dc-link voltage. The second stage is a half-bridge series resonant parallel-loaded inverter for ballasting the lamp. Driving of the inverter switches can be accomplished by two methods. The first is to use a self-oscillating circuit, in which a saturable transformer drives the switches. Typical switches are bipolar transistors. The second is to use a ballast integrated circuit (IC) and the switches are usually MOSFETs. The self-oscillating inverter is the dominant solution, because the circuit is simple, robust, and cost effective [1].

Actually, electronic ballasts are basically switching power supplies that eliminate the large, heavy, 'iron' ballast and replace it with an integrated high frequency inverter / switcher. Current limiting is done by a very small inductor, which has sufficient impedance at the high frequency [2]. For simplify the circuit of electronic ballast and reduced its cost, some single-stage electronic ballasts have been proposed by integrating PFC circuit into the inverter stage to perform both

functions of the PFC and a resonant inverter. By sharing the active power switch and the control circuit, the component count can be effectively reduced [3].

Electronic ballasts utilizing transistor inverters are in use for quite sometime and it is well known that energizing the lamp with a high frequency supply results in several advantages like increased efficacy, no flicker or stroboscopic effect, instant start even at low supply voltage, reduced heating load on air conditioning system and others [4]. The high frequency electronic ballast usually consists of EMI filter, power factor corrector, high-frequency dc/ac inverter, and control circuit. When these circuits are simulated, a suitable model for the main element, fluorescent lamp, is critical.

2.2 Principles Of Operation

Figure 2.01 shows the overall schematic diagram of Unity Power Factor High Frequency Parallel Resonant Electronic Ballast circuit, which has self-base driver, and controller circuit. The circuit consists of full-wave rectifier and conventional push-pull inverter with parallel resonance circuit. Resonance occurs mainly through C , and L_r . Its operation explained as follows. In the steady state, the resonant voltage V_c becomes sinusoidal waveform. This voltage continues to turn the $Q1(Q2)$ on and simultaneously turn the $Q2(Q1)$ off in synchronization with the zero crossing points of the resonant voltage, and the zero voltage switching conditions of transistors are satisfied. In the driver circuit, diode bridge rectifier, which connected to the transformer leg 3, plays a role to supply the transistor base current steadily through proper filtering network. As a result, the square wave current flows into the bases of the transistors [5].

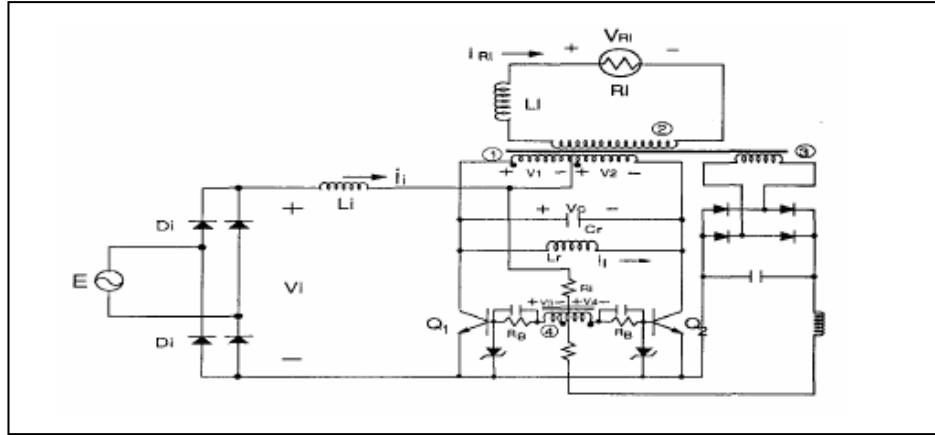


Figure 2.01: Schematic diagram of Unity Power Factor High Frequency Parallel Resonant Electronic Ballast

The new proposed single-switch single-stage electronic ballast circuit is shown in Figure 2. It includes a single-phase voltage supply, a lower conduction losses boost PFC circuit formed by L_{in} , S , C_1 , a diode bridge rectifier formed by D_3 , D_4 , D_5 , and D_6 , two fast-recovery diodes D_1 and D_2 , a push-pull converter for high-frequency supply to the lamp formed by an isolated transformer, S , C_1 , C_s , L_s , C_p , a fast-recovery diode D_7 , and a fluorescent lamp. The power switch S operated at fixed frequency with a constant duty cycle of 50%. The boost PFC circuit operated in discontinuous conduction mode, the input current naturally follows the sinusoidal waveform of the input voltage, achieving unity power factor to the utility line [3].

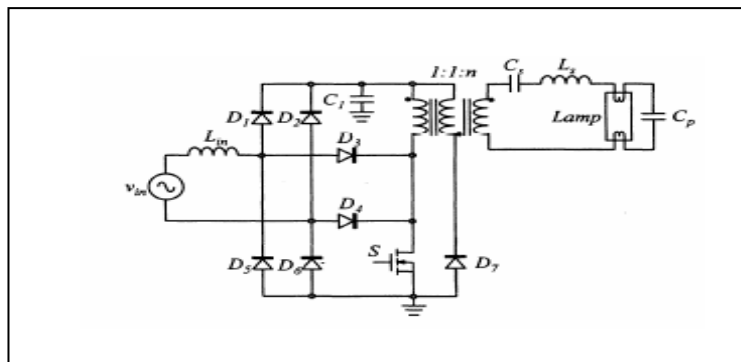


Figure 2.02 : A Novel Single-Switch Single-Stage Electronic Ballast With High Input Power Factor

2.3 Power Factor Control Methods [6]:

A typical active P.F.C. circuit supplies a regulated DC bus at higher voltage than the maximum peak voltage of the AC supply and uses a simple boost topology as shown in Figure 3. The boost topology of Figure 3 may be operated at constant high frequency with continuous inductor current or in the critical conduction mode where the inductor is allowed to discharge to zero energy in before initiating a new charge cycle.

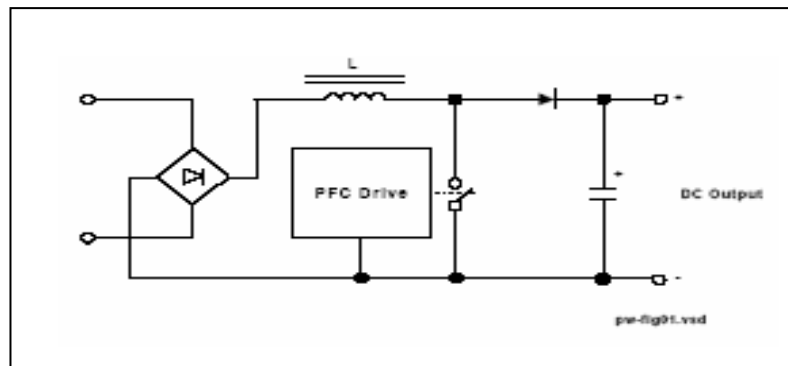


Figure 2.03 : Active PFC Circuit

Passive PFC circuit on Figure 2.04 operates at mains frequency (50 or 60Hz) using capacitors and iron cored inductors tuned to the line frequency in a low pass or band pass configuration. Unfortunately, the physical size and weight of these filters at mains frequency makes them unattractive, especially when one considers that the rest of the ballast circuitry can be smaller than the PFC components.

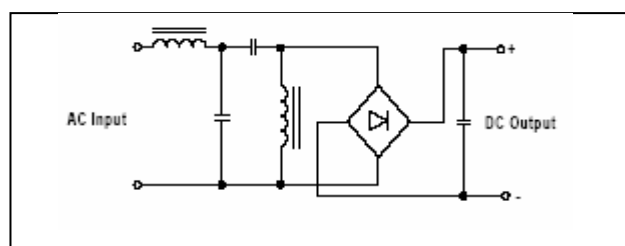


Figure 2.04: L-C Passive PFC Circuit

2.4 Square Wave Ballast [7]

Square wave ballasts eliminate the flicker problem. Square wave ballast maintains a virtually constant output of light over the whole AC cycle by squaring off the curves of the AC sine wave. The change over period is so brief that the light is virtually continuous. Square wave ballasts completely process and regulate the input power, and as a result, they can tolerate fairly wide voltage and Hertz rate discrepancies.

Typical 120V electronic ballast can take an input from 95V to 132V without affecting the output signal and the fixture's color temperature. The refined signal also increases the light output by 6% to 8% and increases globe life as much as 20%. Unfortunately, the square wave causes the globe and igniter to buzz. The head becomes a resonating chamber, amplifying the noise and projecting it out toward the set and the microphones. To make the ballasts quiet when recording dialogue, electronic ballasts are fitted with a switch to change between flicker free operation and silent operation. In the silent mode, a special circuit electronically rounds off the sharp corners of the square wave, which eliminates the noise. In the silent mode, most square-wave ballasts provide flicker-free light at frame rates up to about 34 frames per second (fps), and in flicker-free mode, up to 10,000 fps.

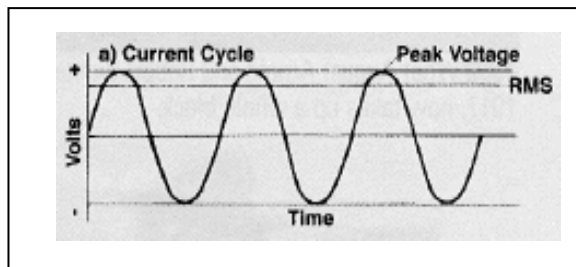


Figure 2.05 : The normal sinusoidal 60 Hz current cycle of magnetic ballast

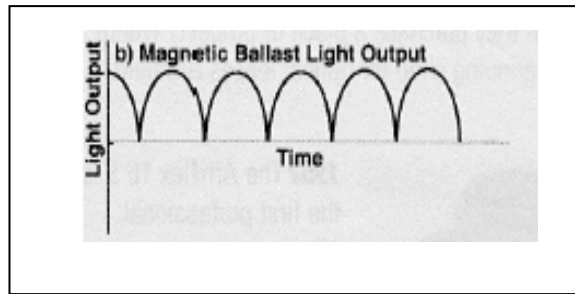


Figure 2.06 : Creates a fluctuating light output

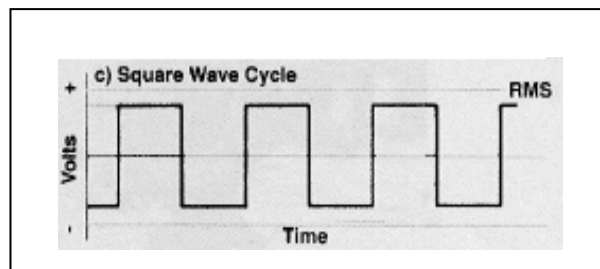


Figure 2.07:.Requirement that the camera frame rate be synchronized with the light fluctuations to obtain even exposure frame to frame. The refined square wave signal of electronic ballast

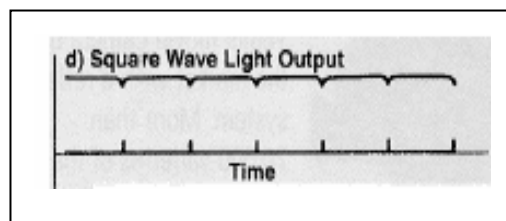


Figure 2.08: Creates virtually even light output

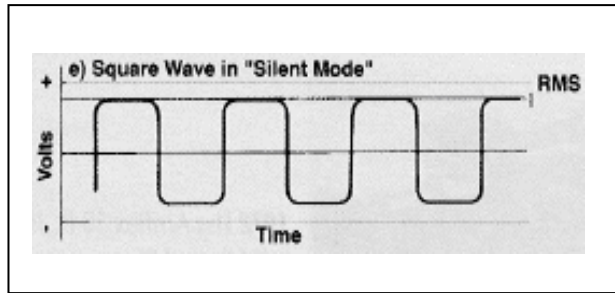


Figure 2.09 : Rendering the fixture flicker-free. The sharps corner of the normal square wave signal creates noise in the head. When operated in silent mode, the ballast electronically rounds off the corners of the square wave.

2.4 Electronic Ballast Analysis [8]

During Ignition:

The resonant capacitor C_u and inductor L_2 will provide enough high ac voltage during the start-up transient to make lamp ionization. The circuit can be described as four states of operation in one cycle,

State I(Figure 2.10)

The transistor M_2 is turned on at $t = t_o$, with M_1 off because of the presence of L_1 , M_2 is turn on with zero-current. C_2 is discharged to R_L . These components will resonant for nearly half a cycle and then stops because D_2 and D_1 are reverse biased.

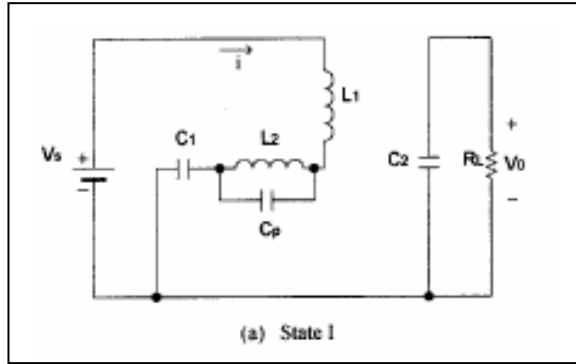


Figure 2.10 : Circuit analysis in state 1

State II (Figure 2.11)

The device current and inductor current are zero. C_2 is still discharges to R_L , M_2 is switched off at zero current condition at $t = t_2$.

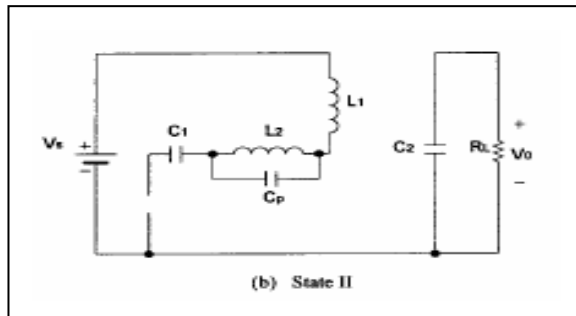


Figure 2.11 : Circuit analysis in state 2

State III (Figure 2.12)

M_1 is turned on at $t = t_2$ with the zero current. When R_L is large, the output voltage V_0 is a constant and can be looked as a voltage source. C_2 is charged by L_1 . After i resonate back to zero value, D_1 and D_2 are in reverse biased and this state terminates.

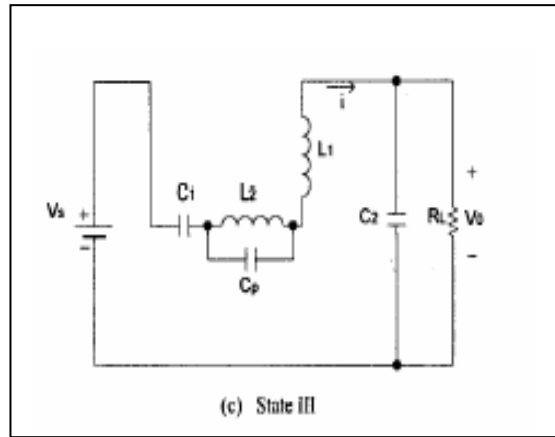


Figure 2.12 : Circuit analysis in state III

State *IV*(Figure 2.13)

i is zero and C_2 is discharged to R_L . M_I is turned off at zero-current when $t = t_4$.

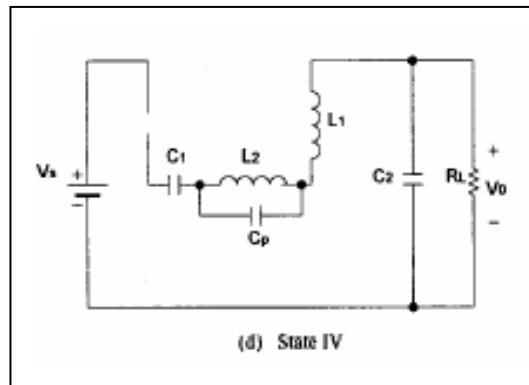


Figure 2.13 : Circuit analysis in state IV

2.5 Ballast Controller IC (IR2156) [9]

The IR2156 is a high voltage half-bridge gate driver with a programmable oscillator and state diagram to form a complete ballast control IC. The IR2156 features include programmable preheat time, programmable preheat and run frequencies, programmable dead time and programmable over-current protection. In electronic ballast, the IR2156 can be function in protection from failure of a lamp to strike, filament failures as well as an automatic restart function.

The IR2156 IC has five modes of operation in electronic ballast circuit. One of operation mode is under-voltage Lock-Out Mode (UVLO) that defined as the state the IC is in when VCC is below the turn-on threshold of the IC. This mode is function to maintain an ultra low supply current of less 200uA and to guarantee the IC is fully functional before the high and low side output drivers are activated.

The second mode in IR2156 is Preheat Mode (PH). This mode is defined as the state the IC is in when the lamp filaments are being heated to their correct emission temperature. This is necessary for maximizing lamp life and reducing the required ignition voltage. This IC enters preheat mode when VCC exceeds the UVLO positive-going threshold.

The other operation mode of IR2156 is Ignition Mode (IGN). This mode is defined as the state the IC is in when a high voltage is being established across the lamp necessary for igniting the lamp. The IR2156 will enter the ignition mode when the voltage on pin CPH exceeds 13V.

The next operation is Run Mode (RUN). In this mode, the ballast will enter the run mode when the lamp has successfully ignited. The run mode is defined as the

state the IC is in when the lamp arc is established and the lamp is being driven to a given power level.

The last mode is Fault Mode (FAULT). In this mode, the IC will enter the fault mode when the voltage at the current sensing pin, CS exceed 1.3 volts at any time after the preheat mode and cause the both gate drivers outputs, HO and LO are latched in the low state. For this time, CPH is discharged to COM for resetting the preheat time and CT is discharged to COM for disabling the oscillator. The IC picture is shown in figure 2.14. For more information about IR2156 IC, refer to the appendix B.

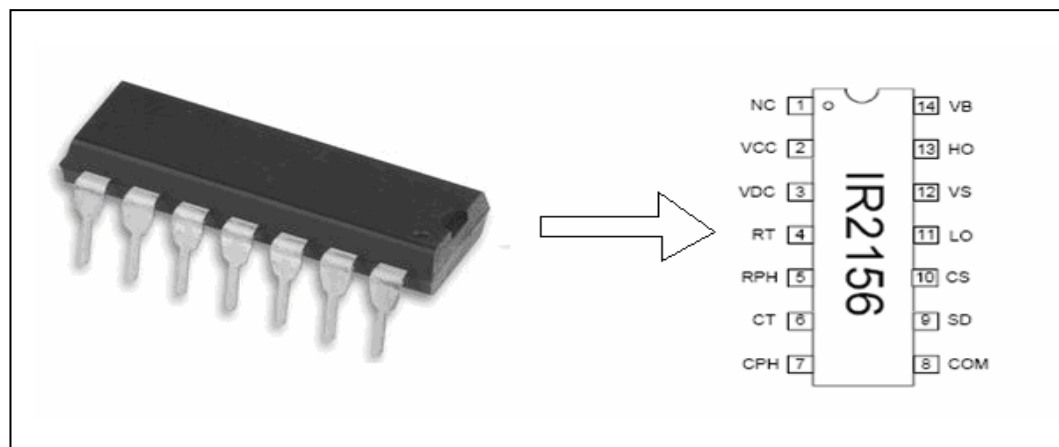


Figure 2.14: IR2156 IC

2.6 Fluorescent Lamp [10]

A fluorescent lamp is a gas-discharge lamp that uses electricity to excite mercury vapor in argon or neon gas, resulting in a plasma that produces short-wave ultraviolet light. Unlike incandescent lamps, fluorescent lamps always require a ballast to regulate the flow of power through the lamp. In common tube fixtures (typically 4 ft (120 cm) or 8 ft (240 cm) in length), the ballast is enclosed in the

fixture. The main principle of fluorescent tube operation is based around inelastic scattering of electrons. Fluorescent lamps are negative resistance devices, so as more current flows through the electrical resistance of the fluorescent lamp drops, allowing even more current to flow. Connected directly to a constant-voltage mains power line, a fluorescent lamp would rapidly self-destruct due to the uncontrolled current flow. To prevent this, fluorescent lamps must use an auxiliary device, commonly called a ballast, to regulate the current flow through the tube. For operation from AC mains voltage, the use of simple inductor (also-called "magnetic ballast") is common. In countries that use 120 V AC mains, the mains voltage is insufficient to light large fluorescent lamps so the ballast for these larger fluorescent lamps is often a step-up autotransformer with substantial leakage inductance (so as to limit the current flow). Either form of inductive ballast may also include a capacitor for power factor correction.

In the past, fluorescent lamps were occasionally run directly from a DC supply of sufficient voltage to strike an arc. In this case, there was no question that the ballast must have been resistive rather than reactive, leading to power losses in the ballast resistor. In addition, when operated directly from DC, the polarity of the supply to the lamp must be reversed every time the lamp is started; otherwise, the mercury accumulates at one end of the tube. Nowadays, fluorescent lamps are essentially never operated directly from DC; instead, an inverter converts the DC into AC and provides the current-limiting function as described below for electronic ballasts.

Some fluorescent designs (*preheat lamps*) use a combination filament/cathode at each end of the lamp in conjunction with a mechanical or automatic switch that initially connect the filaments in series with the ballast and thereby preheats the filaments prior to striking the arc. These systems are standard equipment in 240 V countries, and generally use a glow starter. Before the 1960s, four-pin thermal starters and manual switches were also used. Electronic starters are also sometimes used with these electromagnetic ballast fittings. During preheating, the filaments emit electrons into the gas column by thermionic emission, creating a

glow discharge around the filaments. Then, when the starting switch opens, the inductive ballast and a small value capacitor across the starting switch create a high voltage, which strikes the arc. Tube strike is reliable in these systems, but glow starters will often cycle a few times before letting the tube stay lit, which causes objectionable flashing during starting. The older thermal starters behaved better in this respect.

Once the tube is struck, the impinging main discharge then keeps the filament/cathode hot, permitting continued emission. If the tube fails to strike, or strikes then extinguishes, the starting sequence is repeated. With automated starters such as glow starters, a failing tube will thus cycle endlessly, flashing repeatedly as the starter repeatedly starts the worn-out lamp and the lamp then quickly goes out as emission is insufficient to keep the cathodes hot, and lamp current is too low to keep the glow starter open. This causes visually unpleasant frequent bright flashing, and runs the ballast at above design temperature. Turning the glow starter a quarter turn anticlockwise will disconnect it, opening the circuit.

Electronic ballasts often revert to a style in between preheat and rapid-start styles: a capacitor (or sometimes an auto disconnecting circuit) may complete the circuit between the two filaments, providing filament preheating. When the tube lights, the voltage and frequency across the tube and capacitor typically both drop, thus capacitor current falls to a low but non-zero value. Generally, this capacitor and the inductor, which provides current limiting in normal operation, form a resonant circuit, increasing the voltage across the lamp so it can easily start.

There are three main failure modes currently:

- 1) Emission mix runs out
- 2) Failure of integral ballast electronics.
- 3) Failure of the phosphor :
 - i. Tube runs out of mercury.
 - ii. Phosphors and the spectrum of emitted light.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter focuses on the methodologies for the implementation of electronic ballast project to fluorescent lamp. My circuit project is designed base on half-bridge topology, which mostly used in European with input voltage of 240Vrms and 50Hz frequency.

Before looking at the detail of this project, I like to begin with brief review the relationship of all methods which I need to put into operation. Figure 3.1 shows the correlation between all of the methods of the project.

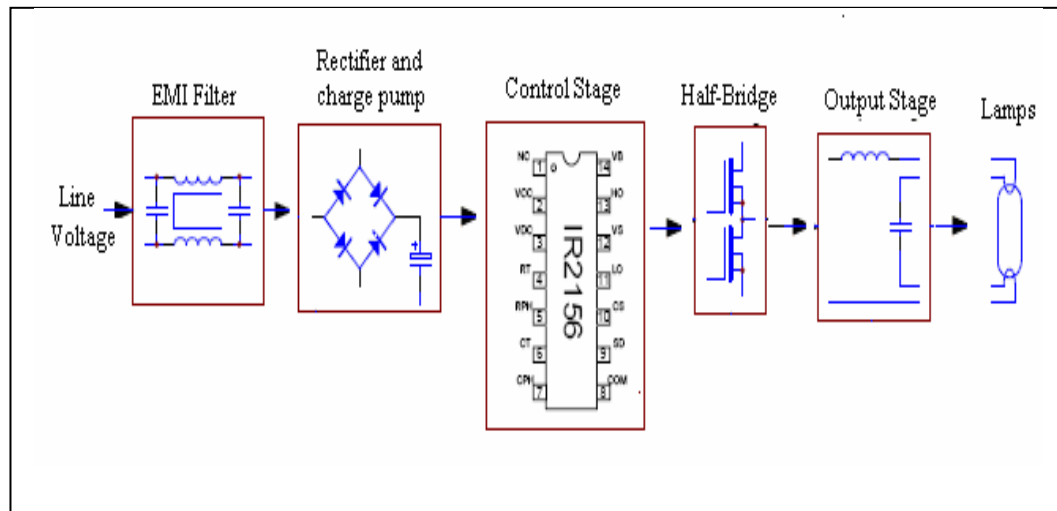


Figure 3.01 : Block diagram for electronic ballast project

From figure3.01, there were six main phases in order to construct the electronic ballast circuit. These six phases are filter, rectifier, control stage, half-bridge, output stage and fluorescent lamp as a load.

3.2 Filtering stage

In the first stage, the input voltage from the AC source with 240Vrms and 50 hertz frequency will flow into the circuit to generate the light of fluorescent lamp. To make sure the fluorescent tube is on, the maximum preheating voltage is about 250Vpk with preheating time around 1 second where the filament are required to strike the arc in ignition mode before the lamp can continuously in on-state. Consequently, it needs more power to ignite the lamp in start-up mode and the life of lamp ballast will be short.

Through this project, the filter stage is one of the important part in electronic ballast circuit. In this stage, I need to use the capacitor, varistor and common mode line filter (ELF-15N007A) which connected to the input line. Since the electronic ballast will generate the high frequency during its operation, the noise frequency signal will be existing in the air system such as during watching the television and listened the radio. The electromagnetic interference (EMI) is a type of noise that produced from high frequency signals during electronic ballast operation. For this reason, the electronic ballast circuit must have filter circuit in the first stage of circuit to avoid the problems occur during watching television and listened radio.

The common-mode line filter N-type (ELF-15N007A) is chosen in first stage of electronic ballast circuit because it can be used to suppress the conductive noise ranging from low to high frequencies generated in this circuit. The LC circuit will acts as filter to reduce the noise and electromagnetic field interference (EMI) in system because the presence of EMI and noise in the system will affect the performance of electronic device. At the same time, the function of varistor is to protect the circuit by absorbing surge voltage. The combination of varistor and LC filter will acts as an insulator at voltage below a predetermined level and the resistance decreases rapidly at voltages above a predetermined level. The combined device operates as an LC filter at low voltage and operates as a varistor at a high voltage.



Figure 3.02: N-series common –mode line filter (ELF-15N007A) is used in filter circuit to filter the noise by attenuating the signal that appear identically on each of the wires going through the filter

3.3 Rectification stage

After the signal that was coming from the AC source was passing through the filtering stage, it will flow through the rectification stage for changing the alternating current (AC) mains line voltage to a direct current (DC) bus voltage. This stage is accomplished by using a full bridge rectifier with rating 1000V and 1A. Actually, the combination of filtering and rectification stage will be functioning to suppress the radio frequency interference (RFI) and voltage transients from the mains. The filter-rectifier circuit at the input can be utilized to obtain a direct voltage from ac mains and then uses self-oscillating resonant high frequency inverter circuit to produce sinusoidal lamp voltage and current with high efficiency and minimum RFI problems. After that, the output DC voltage will be smoothed by electrolytic capacitor. The supply resistor (RSUPPLY) has been chosen to provide two times the maximum start-up current to guarantee ballast start-up at low line input voltage.

3.4 Control stage

An IR2156 ballast controller IC controls the full operation of electronic ballast circuit. The IR2156 is a ballast controller and half-bridge driver in one IC. The IR2156 features include programmable preheat time, programmable preheat and run frequencies, programmable dead time, and programmable over current protection. The power factor correction section contained in the IR2156 forms the control for boost topology circuit operating in critical conduction mode. This topology is designed to step-up and regulate the output DC bus while drawing sinusoidal current from the line (low THD) which is “in phase” with the AC input line voltage resulting in a high power factor.

Across the 2 MOSFETs MHS and MLS is a bootstrap diode DBOOT. This diode is called fast recovery diode (1N4937) that can be used for recovery time of 150ns and providing high efficiency at frequencies to 250 kHz. By providing a path for the inductive current, this device will clamp the spike voltage when MHS or MLS switches off. Since the dV/dt can be pretty high, DBOOT must have a fast turn-on time to make sure that the peak voltage will be clamped to a safe value. A bootstrap diode (DBOOT) and supply capacitor (CBOOT) comprise the supply voltage for the high side driver circuitry to guarantee that the high side supply is charged-up before the first pulse on pin HO.

3.5 High Frequency Oscillator (Half bridge)

In this project, the half-bridge circuit consists of 2 MOSFET transistors, resonant inductor, capacitors and diodes. From rectification stage, the switching regulator charges the electrolytic capacitor that acts as an energy reservoir. The voltage over the electrolytic capacitor is stabilised by adjusting the MOSFET current. Two MOSFET transistors are used to achieve the stability and reliability in operation.

The type of MOSFETs that were used in this operation are N-Channel type with high voltage rating (400V) that are called IRF720 because the breakdown voltage for standard line 230Vac nominal line must be more than 374V. This type has been selected because the characteristics of IRF720 are fast switching, ease of paralleling, simple drive requirements, low on-resistance, and cost-effectiveness.

In this stage, when the half-bridge is oscillating, capacitor CSNUB, diodes DCP1 and DCP2 will form a snubber/charge pump circuit, which limits the rise, and fall time at the half-bridge output and also supplies the current to charge capacitor

CVCC2 to the VCC clamp voltage (approximately 15.6V) of IC1. When the rising under-voltage lockout threshold of IC1 reached, it starts to oscillate and drive MOSFET to boost and regulate the bus voltage to 400VDC. The power factor control starts only during preheat, so the bus is not yet boosted when the oscillator starts. Therefore, this will help to prevent the lamp flash at the start up.

In current mode drive, the steady-state current in the fluorescent tube is limited by the external inductance, LRES. The value of LRES is derived from the impedance one must set in series with the lamp to get the right output power. Depending upon the values of L and C, assuming the DC resistance R is negligible and the operating frequency is nominal, the current waveform will be truncated at the peak value either of the sine (worst case) or during the negative going slope. Obviously, in the second case, the turn off switching losses will be lower. The dynamic behaviour of the transistor must be stable to make sure that the frequency stays within the predicted limits.

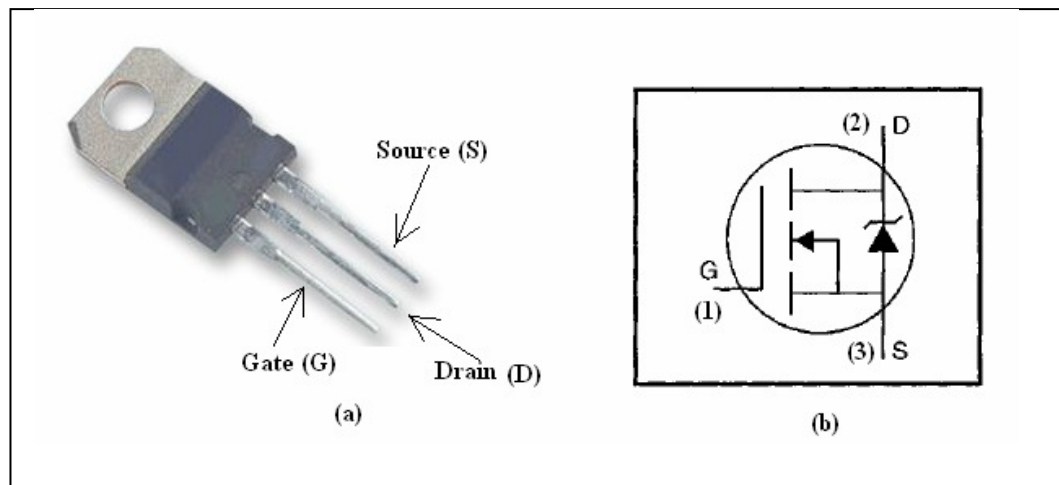


Figure 3.03: IRF720 half-bridge MOSFET (a) and its symbol (b)

3.6 Final Stage

When the circuit energized by turning on the power transistor, while the fluorescent tube is off, the circuit behaves as a series LC circuit (since lamp impedance is infinite low) with its own resonant frequency. This generates the necessary high voltage across the capacitor, permitting early ionisation of the medium inside the fluorescent lamp. During this period, the lamp current flows through the filament that is also in series with the capacitor, causing easy ionisation in the lamp. The magnitude of current is limited by the value of series inductor.

When the tube is fully ionised, the arc is struck, causing its impedance drop to a low value depending on the lamp characteristics. This increases the damping across the capacitor, shifting the resonant frequency. However, the lamp current keeps flowing through the filaments to extract maximum lamp life.